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# REDUCTION OF NOISE FROM A FAN STAGE FOR A TURBOFAN ENGINE BY USE OF LONG-CHORD ACOUSTICALLY-TREATED STATOR VANES

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# REDUCTION OF NOISE FROM A FAN STAGE FOR A TURBOFAN ENGINE BY USE OF LONG-CHORD ACOUSTICALLY-TREATED STATOR VANES

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## ABSTRACT

A set of acoustically-treated long-chord vanes was designed to replace the vanes in an existing fan stage to investigate the noise reduction possibilities of both increased stator chord length and this method of incorporating acoustic damping material. The vanes were tested with both active and inactive acoustic surfaces. The inactive tests showed significant broadband noise effects with noise reductions in the middle to high frequencies and an increase at low frequencies. No reduction in blade passage tone was observed, but decreases in the overtones were observed. The tests with the active acoustic treatment showed large noise reductions over a wide frequency range.

## INTRODUCTION

One of the noise generation mechanisms in a fan stage for turbofan engines is the interaction of the rotor wakes with the downstream stator vanes. Increasing the stator chord is indicated by theory to be a means of reducing the noise generated by this machanism. A set of extremely long chord stator vanes was designed to replace the stator vanes in an existing full scale fan stage (described in ref. 1) to investigate the noise reduction possibilities of increased stator chord.

The long vanes consisted of a turning section whose chord was 0.61 meter (24 in.), or 9 times the chord of the original stators, and axial extension pieces that were added behind the turning section to give a total length of approximately 2.49 meters (98 in.), or 37 times the axial length of the original vanes. Because of the long chord and relatively large thickness, it was possible to incorporate acoustic damping material in these stator vanes. The long acoustically-treated stator vanes could thus replace conventional (ring type) acoustic exhaust splitters. Because of the large thickness involved, such long chord stator vanes could also replace the struts normally used to carry structural loads between the engine core and the outer frame.

The long-chord stator vanes were tested at the Lewis Research Center with the acoustic material active and with the acoustic material covered by metal tape to make it inactive. A photograph of the long-chord stator vanes with the axial extension pieces is shown in figure 1 along with the original stator version it replaced. In this photograph the long-chord vanes are covered with metal tape. The original stage had 112 stator vanes and had the blade passage frequency "cutoff". The long-chord stage had only 14 vanes which resulted in a violation of the cutoff criteria.

The acoustic data taken with the inactive long-chord stator vanes are compared with the acoustic data taken with the original stator version to show the effects of chord length. The active vane data are then compared with the taped vane data to show the effect of this method of incorporating acoustic lining material.

# THEORETICAL BACKGROUND

This section will discuss both the theoretical effects of the longer stator chord on the tone noise and on the broad band noise. In the original 1.83 meter (6 ft) diameter fan stage, the blade passage tone and harmonics are believed to arise primarily from two sources: the rotor wakes impinging on the stator vanes (rotor-stator interaction); and an inlet flow distortion impinging on the rotor baldes. The broadband noise sources include turbulence interacting with a fan blade, shed vorticity from a blade, scrubbing of flow over blade surfaces and the fan duct surfaces, and local flow separations.

## Blade Passage Tone and Overtones

Rotor-stator interaction. - One of the purposes of the inactive long-chord stator vanes was to reduce the blade passage tone and its harmonics generated by rotor wake-stator interaction. A number of researchers have formulated models to predict the noise from this mechanism by calculating the fluctuating lift of the stator vanes as they are struck by the rotor wakes. Examples of these models are given by Kemp and Sears (ref. 2) and Horlock (ref. 3). Portions of some of these models were used in a previous report (ref. 4) to form an expression for the fluctuating lift. Since the same rotor is used in both fan stages (original and long-chord stators), the magnitude of the lift fluctuation, calculated from reference 4, reduces to:

$$|\Delta L| = \left| C_1 \left[ |S(\omega)| - C_2 |T(\omega)| \right] \right|$$

where

$\Delta L$ fluctuating lift

$|S(\omega)|$ magnitude of transverse response function

| | |
|---|---|
| $\|T(\omega)\|$ | magnitude of longitudinal response function |
| $C_1$ and $C_2$ | constants, the same for both fan stages |
| $\omega = \pi C_s/\ell$ | reduced frequency |

where

| | |
|---|---|
| $C_s$ | stator chord |
| $\ell$ | incoming gust wave length |

This expression indicates that the noise reduction should come through changes in the magnitudes of $S(\omega)$ and $T(\omega)$.

An increase in the stator chord, $C_s$, increases the reduced frequency parameter $\omega$ which in turn brings about a reduction in the response functions $S(\omega)$ and $T(\omega)$. With the chord length increase of the long-chord stators (9 times the original chrod) the predicted reduction in the rotor wake-stator interaction blade passage tone and the first harmonic would each be about 9 decibels. (Only the chord increase is used here since the axial extension pieces should not contribute to the reduction of the lift fluctuations). A more detailed theoretical calculation for this fan is given in reference 5.

Inlet flow distortion. - From the previous work reported in reference 1, one of the major sources of blade passage tone noise on this test facility was the interaction of an inlet flow distortion with the fan rotor blades. Since this inlet flow distortion noise was so strong, any possible reduction in the rotor-stator interaction blade passage frequency noise would be masked by the distortion generated rotor-alone noise and thus probably would not be discernable in the far field. However, the harmonics of the blade passage tone were not everywhere dominated by the inlet flow distortion. The data of reference 1 and the analysis in reference 5 indicate

that the overtones of the blade passage tone were not as greatly affected at the rear angles by the inlet flow distortion as was the blade passage tone. The changes in the rotor-wake stator generated noise brought about by the long stator chord may then be observed in the overtones particularly toward the rear of the fan.

## Broadband Noise

The internally-generated broadband noise comes from many sources. These include turbulence interacting with a fan blade, the shed vorticity from a blade and by the scrubbing of flow over blade surfaces, and local flow separation to name a few. Some of these noise sources should be reduced by the longer stator chord and some should be increased.

The broadband noise generated by turbulence interacting with the stator blades was expected to be reduced by the increased stator chord. Lieppman (ref. 6) and Goldstein, et al (ref. 7) have expressed the broadband acoustic power that could be generated in a turbulent flow as a function of the Sear's function, $S(\omega)$, mentioned previously. According to this theory an increase in the stator chord should result in a reduction of the turbulence interaction broadband noise probably at the higher frequencies.

The broadband noise generated by scrubbing over the stator surfaces, by the vortex shedding of the longer stator and by increased wake turbulence would probably be increased in the long stator configuration. In view of the nature of vortex shedding and wake turbulence noise the increase with the large stators would probably be at the lower frequencies. Other increases in broadband noise could result from separated flow and possible local shock regions.

## Synopsis of Expectations From Theory

The theoretical reduction in the rotor wake-stator interaction tone noise will probably only be observed in the overtones and not in the fundamental. Furthermore, inasmuch as the vane-blade ratio was selected for cutoff of the fundamental tone in the original design but not in the long chord design, this violation of the cutoff criterion could also result in the negation of some of the predicted fundamental tone reduction. The longer chord concept by itself could be incorporated in a fan stage without violating cutoff but to observe the effect of very long chords the cutoff criterion was violated in this long chord design. The harmonics for both fan stages (original and long chord) are not cutoff, and this factor should have no effect on the harmonics.

The broadband noise should be reduced at certain frequencies as a result of the longer chord reducing the blade response to incoming turbulence. Broadband noise from vortex shedding, scrubbing, etc., should probably be increased with the longer chord. The net result is not predictable but should probably consist of reductions at certain frequencies and increases at other frequencies.

# APPARATUS AND PROCEDURE

## Fan Stages

Acoustic data from two full-scale 1.83 meter (6 ft) diameter fan stages, tested on the Lewis Outdoor Fan Test Facility differing only in stator design, were used in the course of this study. The first fan was a 1.5 pressure ratio, 337.4 meters per second (1106 ft/sec) tip speed fan designated as QF-2 (ref. 1). This fan had 53 rotor blades and 112 stator vanes. Acoustic data for the QF-2 fan were presented in reference 1,

and will be used as the baseline for deducing the effect of the long stators.

The second fan tested, as a part of this study, designated QF-1A was the long chord stator design. This fan used aerodynamically the same rotor as the QF-2 stage (same aerodynamic design built for opposite direction of rotation) with significantly redesigned stators. There were 14 stator vanes in the QF-1A stage with a 6 centimeter (24 in.) chord in the turning section and a total length of approximately 2.49 meters (98 in.) with the axial extension pieces added behind the turning section.

## Long-chord Stator Design

The long-chord stators were designed to achieve, as closely as possible, the same aerodynamic performance as the original QF-2 stators while incorporating a much longer chord. The incorporation of this concept into an existing test facility coupled with the desire for ease of fabrication had considerable impact on the design of these stator vanes.

An illustration of the QF-2 fan nacelle assembly with the original 112 vanes is shown in figure 2. The centerbody of the assembly is supported by one large pylon in this test facility. The presence of this thick pylon caused a flow restriction in the fan annulus with the long chord stator vanes and dictated portions of the stator design. Figure 2(a) shows the QF-2 fan with a cylindrical hardwalled inlet and figure 2(b) shows the acoustic inlet with acoustic splitter rings used in the active long-chord stator tests. This acoustic inlet is the same inlet used in reference 8 and is described in detail there.

Developed view sketches of the fan with the original fan stage and the long stator vanes are shown in figures 3(a) and 3(b), respectively. (Not all of the rotor blades and stator vanes are shown on these sketches).

Figure 3(b) shows the arrangement of the long-chord vanes. On this figure the trailing edge of stator 5 was faired into the pylon leading edge. Because of the flow blockage created by the pylon, it was necessary to terminate stator vanes 4 and 6 on either side of the pylon at the same length as vane 5. The incorporation of a slightly longer turning section chord on stator 7 (also 1-3 and 8-14) than on vanes 4, 5, and 6 enabled the area on this side of the pylon to be increased slightly to allow more flow through this channel. On the other side of the pylon it was necessary to contour stator vane 3 around the pylon to relieve the area restriction. Even with these area redistributions, it was calculated that the channels on either side of the pylon and the channel between stator vanes 2 and 3 would be choked at about 90 percent speed point of the fan. It should be noted that in possible flight installations the thickest pylons used are much smaller than the pylon in this test facility and do not pose a serious problem in applying this concept.

A photograph of one of the long-chord stator vanes on a work table is shown in figure 4(a) and a sketch is shown in figure 4(b). The leading edge piece is solid aluminum with roughly a NACA-65 series airfoil thickness from the leading edge back to the location where the thickness was equal to the thickness of the following lined section. The acoustic lining material used on opposite sides of the stator vanes, shown in figure 4(b), was of two different backing depths. The thicker lining material was 0.95 centimeter (3/8 in.) hexcell honeycomb 2.24 centimeters (0.88 in.) thick with a 0.51 millimeter (0.020 in.) thick facing sheet. The perforated facing sheet had 1.14 millimeters (0.045 in.) diameter holes evenly spaced to give an 11% open area ratio. This thicker material has a predicted frequency of

maximum noise attenuation of approximately 2400 Hz. The thinner material was 0.95 centimeter (3/8 in.) hexcell honeycomb 0.81 centimeter (0.32 in.) thick with a 0.51 millimeter (0.020 in.) thick facing sheet. The perforated facing sheet had 1.27 millimeter (0.050 in.) diameter holes evenly spaced to give a 5% open area ratio. This thinner material has a predicted frequency of maximum noise attenuation of approximately 3900 Hz. The two materials were designed using the theory of reference 9. One thickness was placed on each side of a vane so that the different thicknesses face each other across the flow channel formed by two stator vanes. The summation of the two honeycomb thicknesses, two perforated sheets and the septum thickness determined the overall stator thickness of 3.45 centimeters (1.360 in.).

## Test Facility

The experiments reported herein were conducted at the Full-Scale Fan Test Facility at the Lewis Research Center (ref. 10-11). Figure 5(a) shows the test site and figure 5(b) shows a plan view of the test facility. Acoustic data were obtained by 1.27 centimeters (0.5 in.) condenser microphones located at 10 degree increments from 10 to 160 degrees as shown in figure 5(b). The microphones were level with the fan centerline, 5.79 meters (19 ft) above the ground on a 30.48 meter (100 ft) radius. A complete description of the acoustic instrumentation and the data acquisition techniques are given in reference 10.

Three samples of acoustic data were taken at each test condition and averaged to minimize the effect of short-term fluctuations in the generated noise. The data taken at 60, 70, 80, and 90 percent of design speed were recorded on magnetic tape and both a 1/3-octave band analysis and some

constant bandwidth narrow band analysis were performed.

### Test Configurations

Four basic configurations were tested during the course of this study. The first configuration was the fan stage with the original 112 stator vanes and a hardwalled cylindrical inlet which was previously tested and reported in reference 1. The second test configuration was the long-chord stator fan stage with hardwalled inlet tested with the acoustic material made inactive by being covered with metal tape. This second configuration was tested to compare with the first configuration and to insolate the noise reduction effects on increased stator chord.

The third configuration was the long-chord stator stage with inactive (taped) stator but with the three-ringed acoustic inlet. This configuration was performed to give a base configuration for the active stator case, and the inlet was made active so as to reduce noise from the inlet that might otherwise mask the stator vane activation results. The final test was with the acoustic material on the stator vanes made active to determine the results of this method of incorporating acoustic material.

## RESULTS AND DISCUSSION

As previously mentioned, the tests were performed to investigate two areas: the noise reductions possible from long stator chord, and the noise reductions from incorporating acoustic lining material on these long stator vanes.

### Effect of Chord Length

The long-chord stators were run with the hardwalled cylindrical inlet in a taped configuration to indicate the noise reduction possibilities of longer stator chord. Figure 6 gives the 1/3-octave band acoustic power

spectra obtained from this taped stator configuration. The four curves on this figure are for 60, 70, 80, and 90% of fan design speed. Figure 7 shows a series of comparisons between the acoustic power for the original short chord stator vanes (QF-2) and the acoustic power for the long-chord stator vanes with inactive (taped) surfaces. Figure 7(a) is for 60%, 7(b) for 70%, 7(c) for 80%, and 7(d) for 90% of design speed. This comparison shows a number of noteworthy results with the long-chord stators.

Blade passage tone. - As was indicated previously in the "Theory" section, the inlet flow distortion-rotor interaction machanism appears to produce the dominant blade passage frequency noise. In these tests the blade passage tone was not changed with the long chord vanes (fig. 7(a) - (d). (The slight changes at 90% speed is just a shift in the 1/3-octave band containing the tone as a result of day-to-day fan speed changes to obtain constant corrected speeds; when the power is added in the two bands the power levels of the tone are the same). As anticipated, no blade passage frequency noise reduction due to the long-chord stator vanes is visible, probably because the blade passage tone generated by the inlet flow distortion is masking the effect.

Overtones. - The first overtone of the blade passage frequency does show some noise reduction as a result of the change to the long-chord stator (fig. 7(a) - (d)). On acoustic power, this effect was more noticeable at the lower speeds than at the higher speeds. Part of the reason for this is that the inlet flow distortion contribution to the overtone was not as strong at the low speeds, and changes in the rotor-stator interaction noise generation were more easily seen. In addition, the 1/3-octave band containing the first overtone also contains broadband noise which may con-

tribute to the signal level.

To better investigate the effect on the overtone, a number of narrow band spectra were taken. The level of the harmonic was determined from these three samples of narrow band spectra at each $10^{\circ}$ azimuth angle. A plot of the first overtone versus angle along with the QF-2 original stator data is shown in figure 8 for 90% speed. As can be seen, the first overtone was about the same at inlet angles from $10^{\circ}$ to $70^{\circ}$. This is further indication that the inlet flow distortion controlled the first overtone in the front. However, noise reductions are observed at angles beyond $80^{\circ}$ where the rotor-wake stator interaction could be dominant. In fact, beyond $100^{\circ}$, the first overtone was reduced below the level of the broadband noise which in this region of the figure is represented with different symbols.

To further show this result, three narrow-band spectra are presented in figure 9 at 50, 80, and $120^{\circ}$, to show the difference between the front and rear radiated noise. As can be seen, there was little change in the level of the overtone in the front ($50^{\circ}$ fig. 9(a)), but it was reduced toward the rear ($80^{\circ}$ fig. 9(b)) and had disappeared into the broadband at the $120^{\circ}$ microphone (fig. 9(c)). The second overtone was reduced with the long-chord stator vanes as can also be observed in the narrowband data of figure 9.

The reductions in the overtones are not as great as the 9 decibels predicted by the theory. This discrepancy may be due to the presence of inlet distortion noise, or for the rear angles, it may be due to the presence of a broadband noise floor. Nevertheless, reduction in the first and second overtones has been shown as a result of the long-chord stator vanes,

and even more reduction might be expected if other noise sources such as the inlet flow distortion were not present. In this particular fan stage, the perceived noise level was controlled by the blade passage frequency tone and little perceived noise reduction occurred with these overtone reductions. However the reduction in the overtones may be particularly important for STOL type fans with low numbers of rotor blades and low tip speeds where the overtones are the largest contributors to the perceived noise levels. In this case, the longer stator chord could result in a significant perceived noise reduction.

Broadband. - Returning to figure 7, a significant effect of the long-chord stator vanes on the broadband noise is observed. Starting with 60% speed (7(a)), the broadband noise was greatly reduced above 630 Hz with the long-chord stators while a slight increase was observed below 500 Hz. This noise reduction at 60% speed would be most effective during an airplane's approach for landing. As the fan speed was increased, the noise sources generating the increased low frequency noise became stronger, and the emission occurred over a broader range of frequency until at 90% speed (7(d)) the increase was observed in the range from 200 to 1600 Hz. The reduction in the high frequency broadband noise was still observed above the blade passage frequency, but it was not as strong a reduction at the 90% speed point.

The broadband noise reductions at the higher frequencies occurred mostly toward the front of the fan, and the regions of low frequency broadband noise increases occurred mostly in the rear. The data at 80% speed show more clearly than the other data the inlet-exhaust split among the radiated noises. To illustrate the noise split two broadband sound pressure

level plots of specific 1/3-octave bands are shown in figure 10. The first plot 10(a) shows the angular sound pressure level variation in the 1/3-octave band centered at 3150 Hz that was reduced with the long-chord stator, and figure 10(b) shows one of the bands which showed an increase, (630 Hz). In viewing 10(a), the decrease in broadband noise with the long-chord vanes is seen to occur toward the inlet of the fan (from $10^{o}$ to $120^{o}$). This 2/3rds of the arc is where noise due to fluctuating lift on the stator caused by incoming turbulence or rotor wake irregularities would appear. This points to the longer chord reducing the response of the stator vanes to the incoming disturbances thereby reducing the broadband noise in this frequency range. Figure 10(b) shows that the increase in low frequency broadband noise occurred mostly toward the rear of the fan, from $70^{o}$ back. This increase probably occurred on the rear portion of the long chord stator or possibly in the exhaust jet and is an indication that the cause may be increased vortex shedding from the long-chord stators or increased wake turbulence.

To summarize, the decrease of broadband noise observed in the high frequencies was probably a result of the longer stator chord reducing the response of the stator vanes to the incoming turbulence or rotor wake irregularities. The increase in noise at the low frequencies was possibly the result of vortex shedding or wake turbulence from the long-chord stator vanes. The ability to impact the broadband noise output of the fan (particularly the reduction) presumably by only changing the stator, points at least in this fan stage, to the conclusion that the stator controlled the broadband noise. This conclusion, if applicable to other fans, could have a significant effect on future efforts to reduce broadband noise generation.

## Effect of Acoustic Treatment

The long-chord stator vanes were tested both with active and inactive (i.e. taped) acoustic material. An acoustic inlet was incorporated in both configurations (fig. 2(b)) to reduce noise from the inlet that might otherwise mask the stator vane activation results. Figure 11 is a set of figures which show the rear hemisphere sound power spectra for both the active and inactive acoustically treated vanes. Figure 11(a) thru 11(d) are for 60% thru 90% design speeds respectively. As tne figure shows the long-chord stator activation resulted in significant noise reductions over a wide range of frequencies. The most reduction was around the blade passage frequency and very little noise reduction has occurred below 1000 Hz.

An interesting observation can be made by inspecting the noise of the active treatment long-chord stator vanes in comparison with the original short stator vanes. This comparison is shown in figure 12 where figure 12(a) is for 60% and 12(b) is for 90% speed. Here it is seen that the activation of the lining material gave reductions in addition to that achieved by the taped long-chord stator in the middle to high frequencies. However, the activation of the lining material did not remove the low frequency noise that was previously added to the original short stator noise spectra by going to the taped long-chord stator (fig. 7). The failure to remove this low frequency noise is probably the result of the high tuned frequencies of the liners. However, in past experience (for example see ref. 8) acoustic material has removed noise many thousands of Hz away from its "tuned" frequency. Another possible explanation for this is that the increases low frequency broadband noise of the long-chord stator vanes is added downstream of the liner surfaces. This later explanation, if correct,

could then give further indication that the low frequency noise was from increased vortex shedding or wake turbulence.

## SUMMARY OF RESULTS

A set of long-chord stator vanes was designed to replace the conventional vanes in an existing full scale fan stage to explore the effect of stator chord on rotor-stator interaction noise. These vanes had acoustic lining material on their surfaces and were tested with both the lining material active and with the lining material made inactive by covering it with metal tape. It was found that:

1. In comparing the blade-passage tone generated with the taped long-chord stator vanes with that of the original short-chord stator vanes no change was observed. The fact that no blade passage tone reduction was observed was probably due to the fact that an inlet flow distortion-rotor interaction generated noise was the dominant tone source and masked any reduction in rotor-wake stator generated noise.

2. Reductions in the overtones of the blade passage tone were observed with the taped long-chord stator vanes. These reductions were mostly toward the rear of the fan where the inlet flow distortion-rotor interaction noise did not dominate the overtones. In fact, at angles greater than $100^{\circ}$, the first overtone was reduced below the level of the broadband noise. This result provides some evidence for reduction of tone by longer stator chords, even though the reductions observed were not as great as predicted by the rotor wake-stator interacting theory. This overtone reduction would be particularly effective for a low tip speed-low blade number fan stage where the overtone reduction could result in a perceived noise level reduction.

3. The broadband noise output of the fan was greatly affected by the taped long-chord stators. At the medium to high frequencies the broadband noise was significantly reduced in comparision with the original stators, probably as a result of the long-stator chord reducing the stator response to the incoming turbulence and unsteady blade wakes. A noise increase was observed at low frequencies probably as a result of increased vortex shedding and wake turbulence from the long-chord stators. This noise increase was hardly noticeable at low speeds, but continued to grow in magnitude and frequency range until it was significant at 90% speed. The changes observed in the broadband noise, particularly the reductions, indicate that the stator controlled the broadband noise, at least in this fan. This further points to the stator as a profitable area for investigation of broadband noise reduction.

4. Tests run with active acoustic material on the long-chord vanes showed significant noise reductions over a wide frequency range. However, the low frequency noise added by the taped long-chord stator vanes was not removed by the acoustic lining material.

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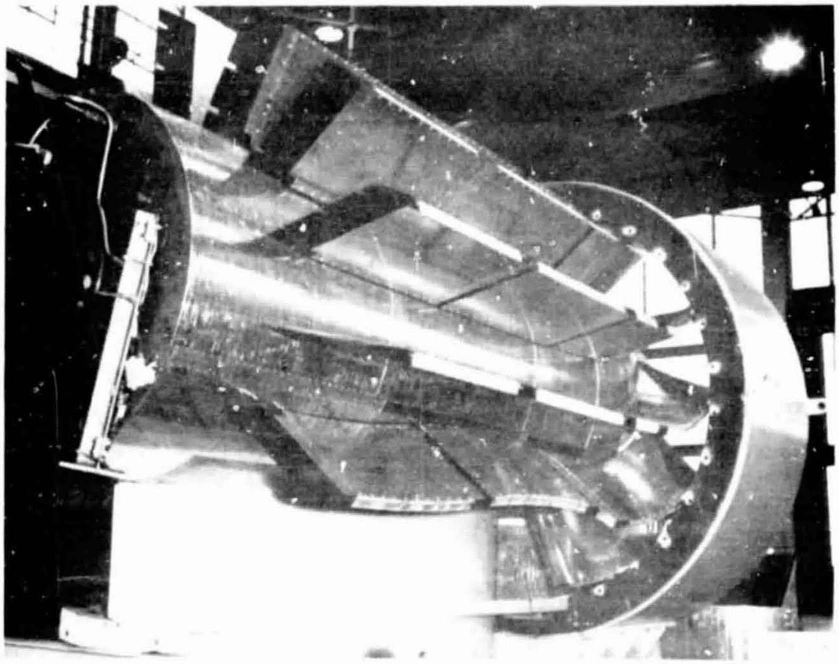
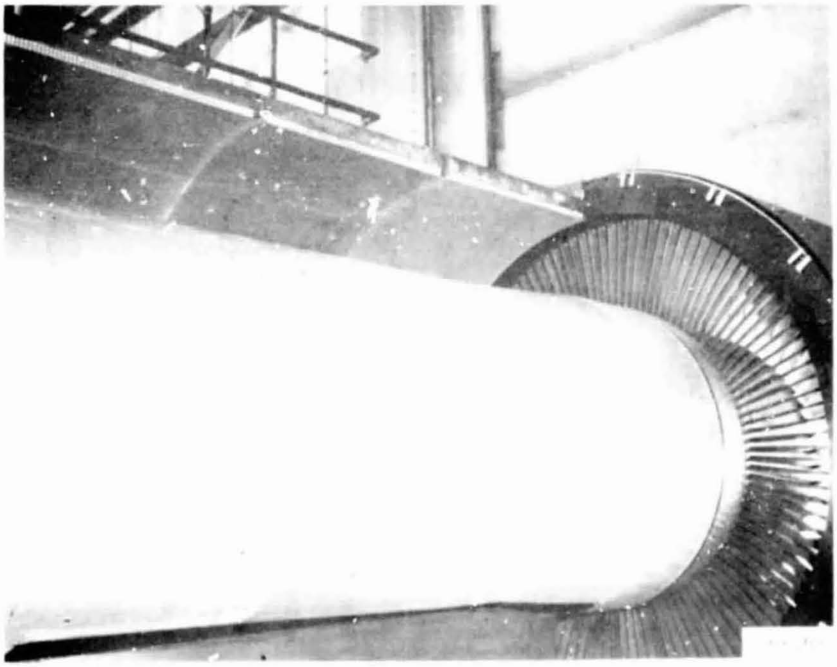
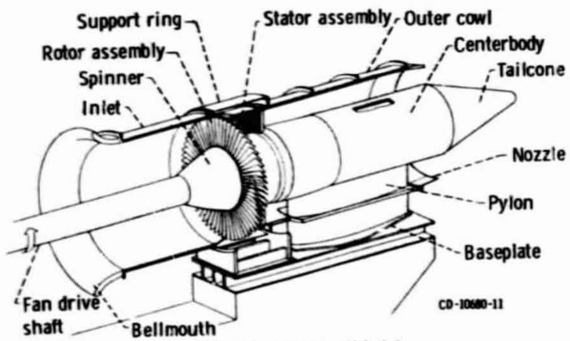


(a) LONG-CHORD STATOR.

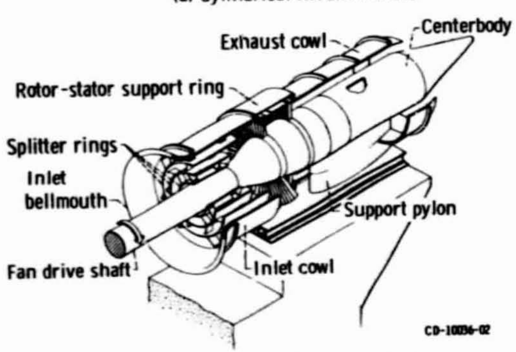


(b) ORIGINAL STATOR VANES.

Figure 1. - Fan stator vanes (viewed from downstream).

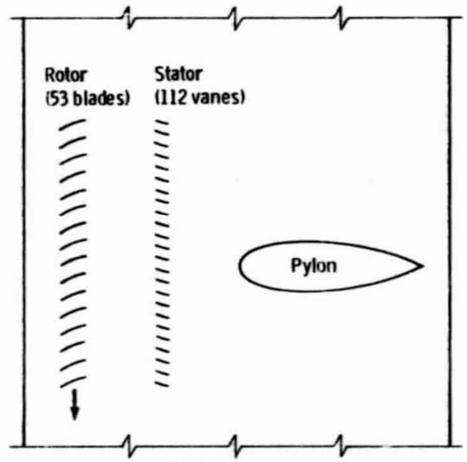



(a) Cylindrical hardwall inlet.

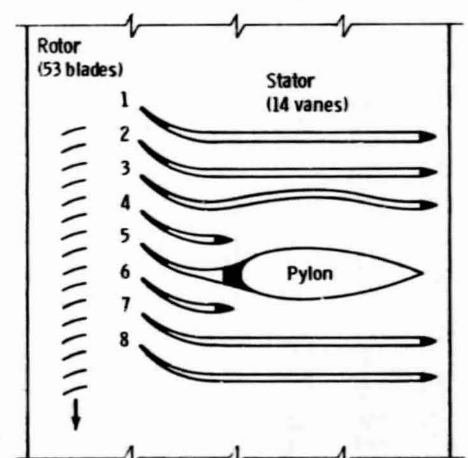



(b) Inlet acoustical suppressor.

Figure 2. - QF-2 fan nacelle assembly.

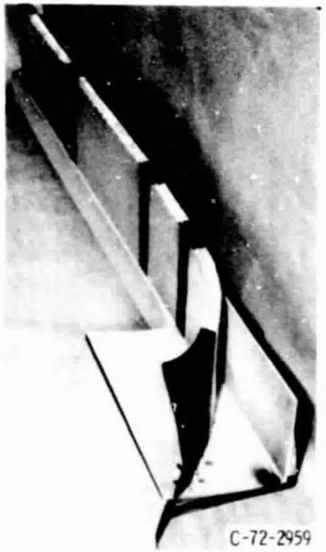



(a) Original fan stage.

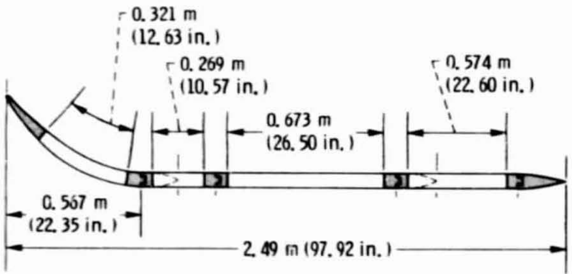



(b) Fan stage with long-chord acoustically treated stators.

Figure 3. - Developed views of fan stages.

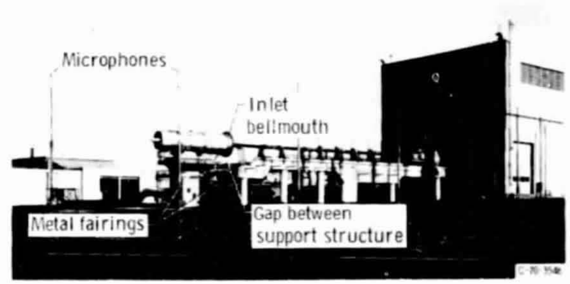



(a) Stator on work table.

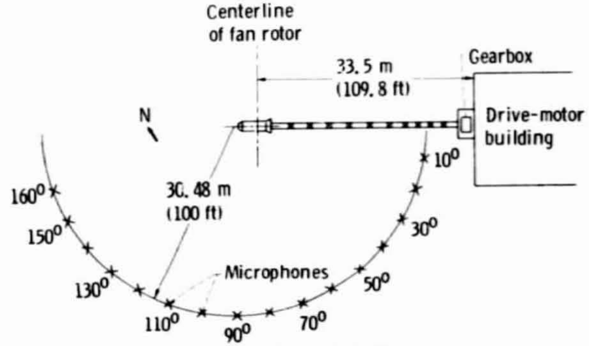



(b) Stator dimensions.

Figure 4. - Long chord stator configuration.




(a) Test site.




(b) Plan view of test site.

Figure 5. - Full-scale fan test facility.

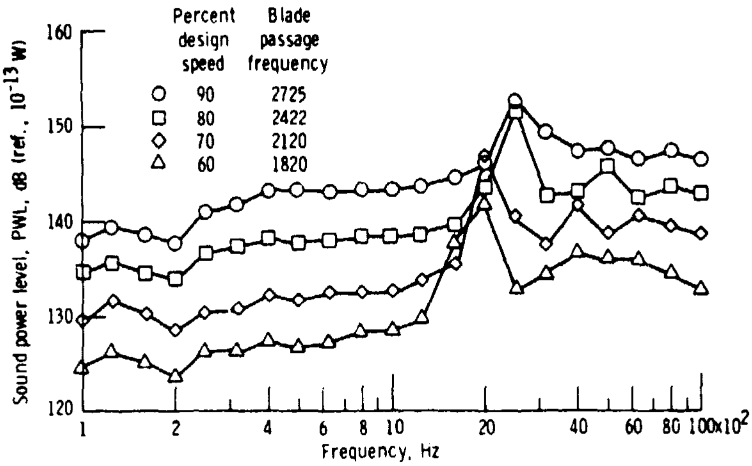



Figure 6. - One-third octave band acoustic spectra for long-chord stator configuration with cylindrical hardwall inlet.

E-8331

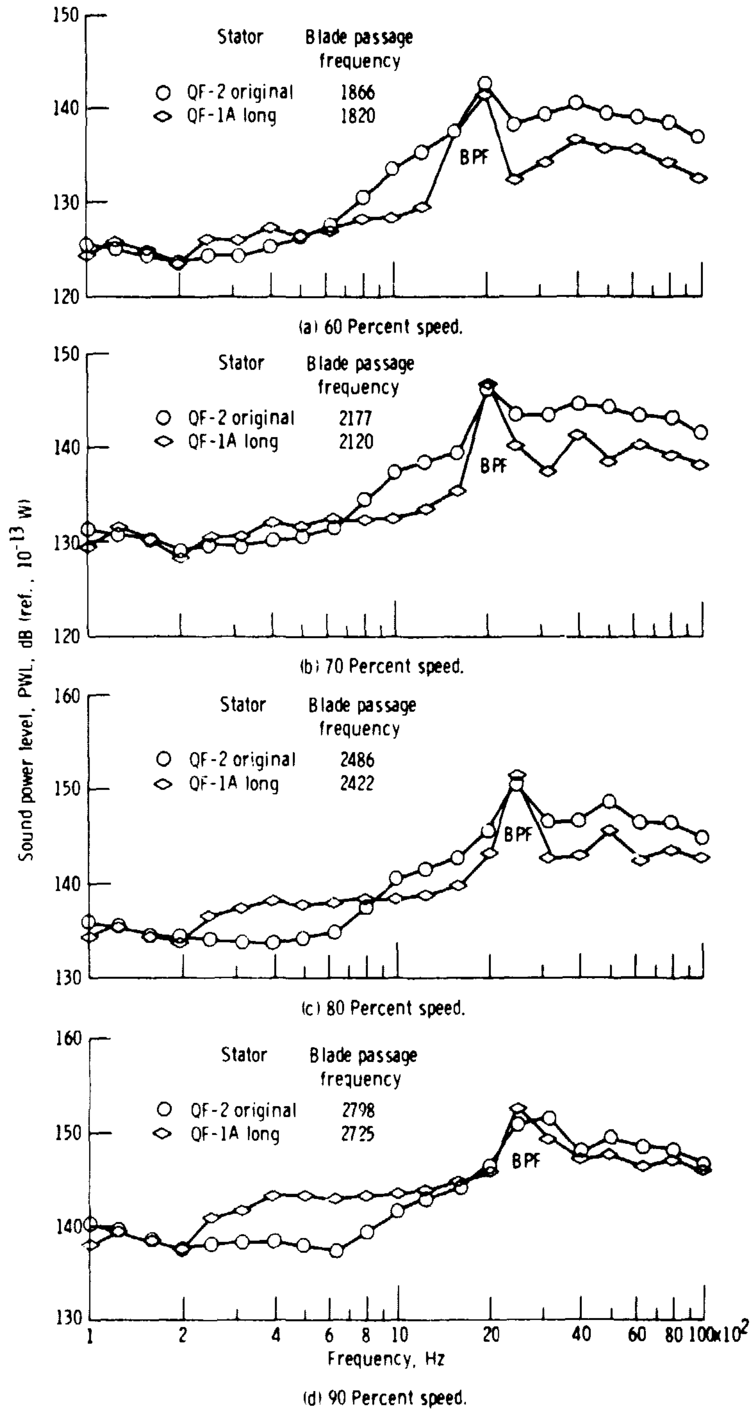



Figure 7. - Comparison of acoustic power spectra for long-chord stator and original QF-2 stator, cylindrical hardwall inlet.

E-8331

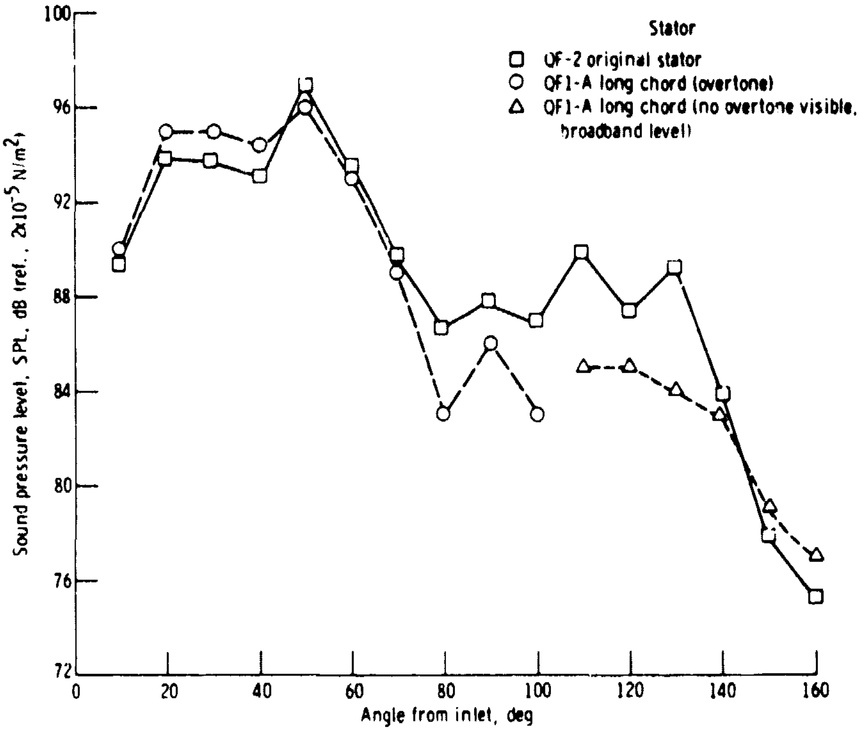



Figure 8. - Angular distribution of first blade passage overtone from narrowband spectra on 30.5-meter (100 ft) radius. Speed, 90 percent.

E-9331

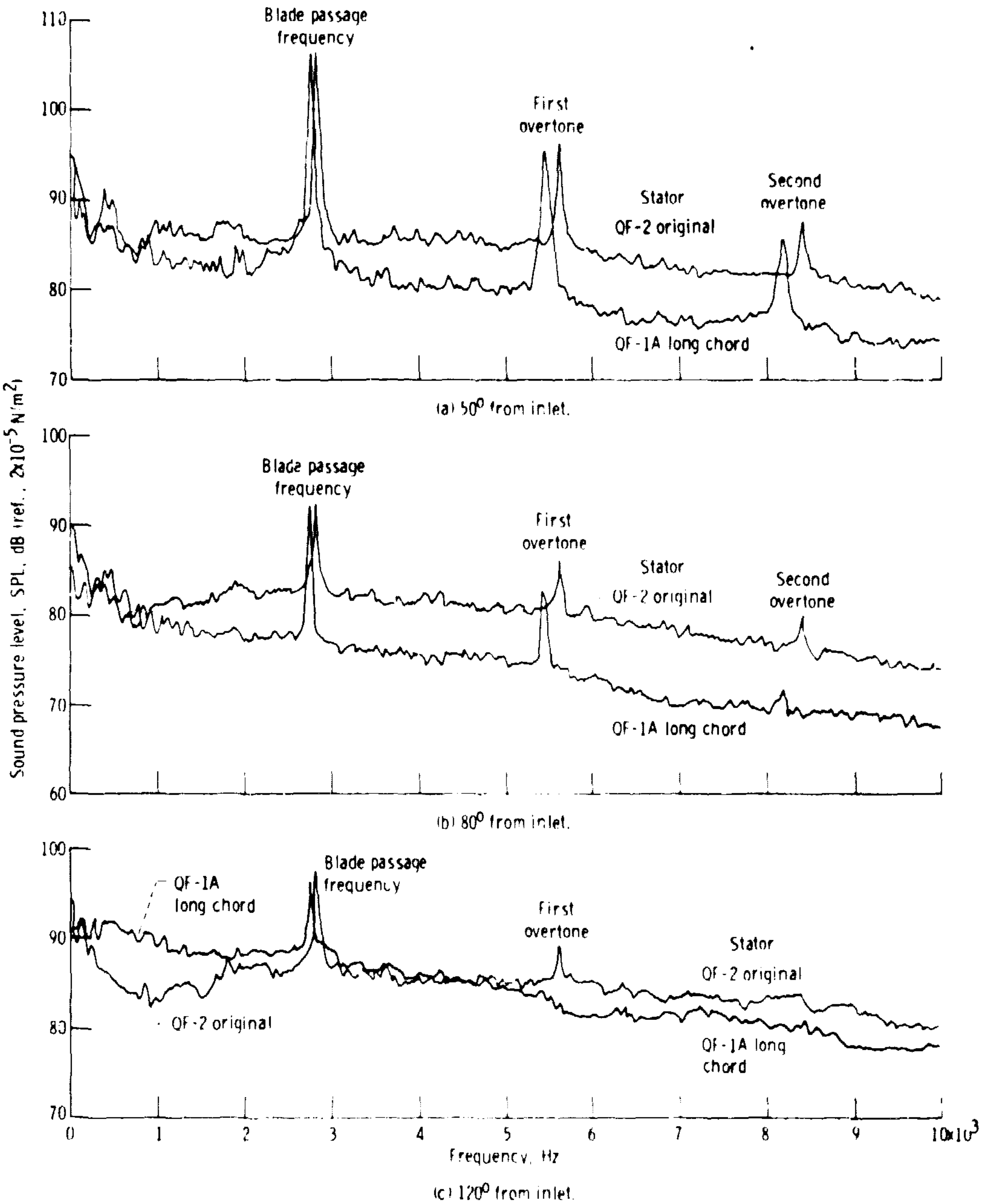
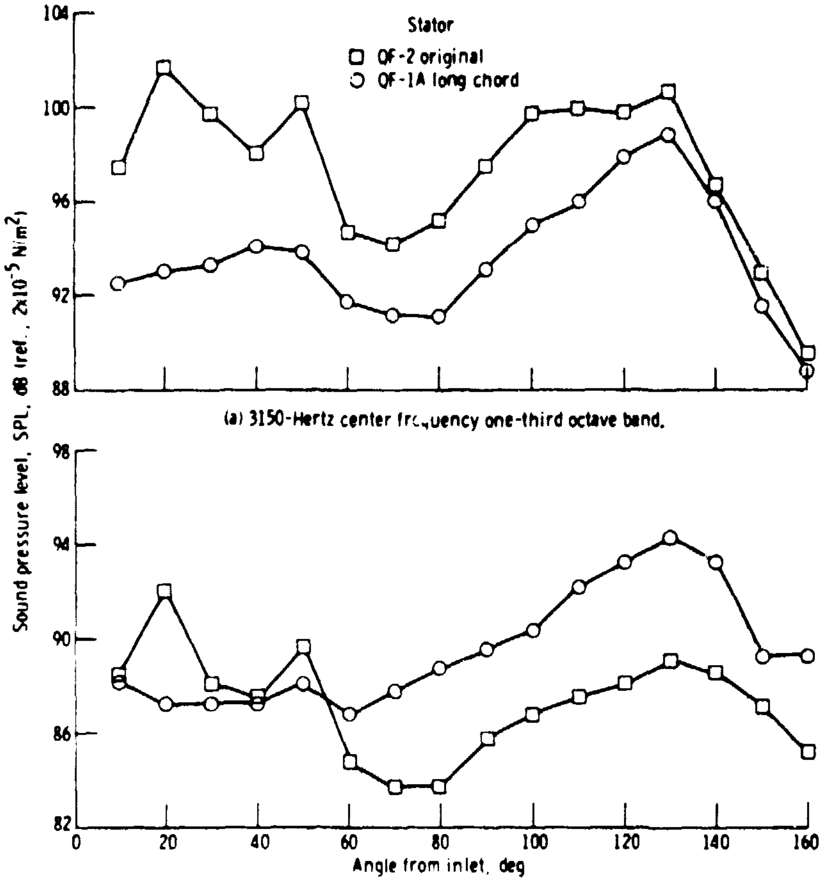



Figure 9. - Comparison of 10-hertz narrowband spectra at 90 percent speed.




(a) 3150-Hertz center frequency one-third octave band.

(b) 630-Hertz center frequency one-third octave band.

Figure 10. - Sound pressure level comparisons with angle at 80 percent speed.

E-8331

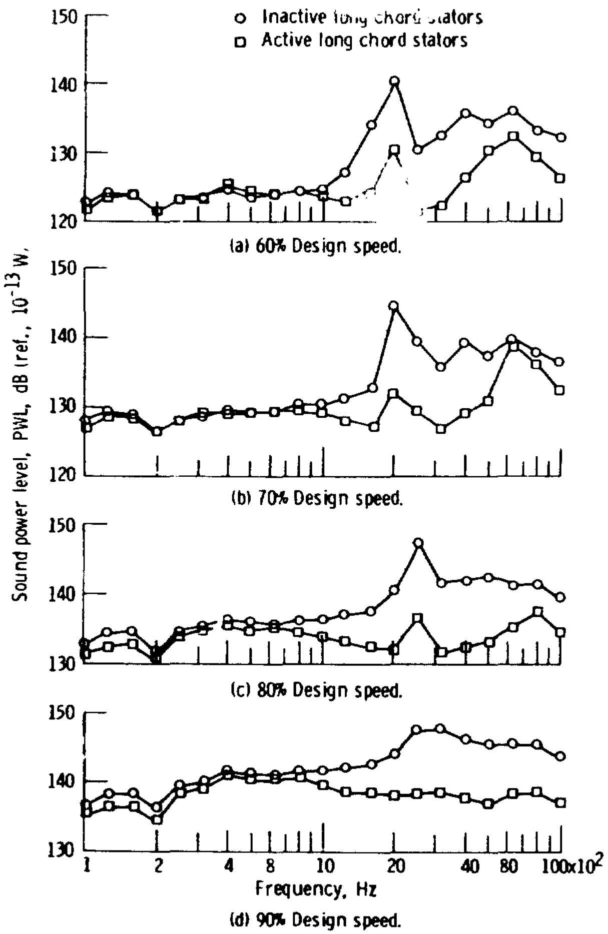



Figure 11. - Rear hemisphere sound power spectra with acoustically treated inlet.

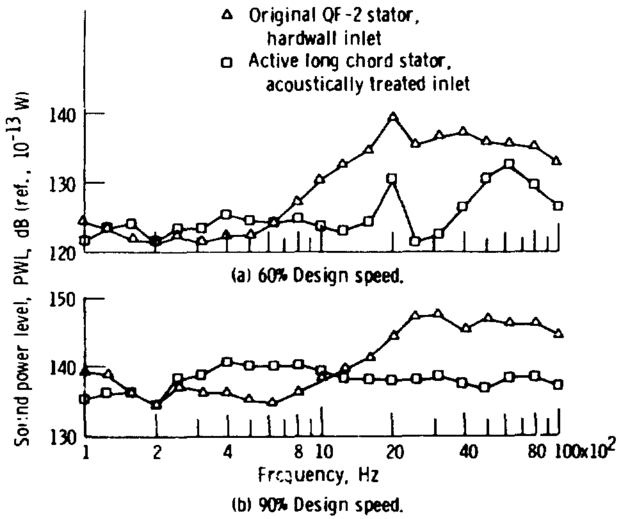



Figure 12. - Rear hemisphere sound power spectra.